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DIGITAL SPECTRAL IDENTIFIER-CONTROLLER

AND RELATED METHODS

Cross Reference to Related Applications. This application is a Continuation-in-Part of Application, Serial No. 09/343,855 filed 06/30/99 entitled Digital Spectral Identifier-Controller and Related Methods.

Field of Invention. This invention is primarily directed to an electronic apparatus and method for identifying objects and species of objects such as plants in an agricultural field. It includes a wide spectrum light scanning and sensor unit having a digital identifier. More particularly, the preferred embodiment includes an apparatus for selectively identifying 1) all plants, 2) all plants other than agricultural crops 3) specific plants within a field, such as weeds of a specific species.

This invention is also directed to a long recognized problem of selectively applying chemicals to specific plants in a field while avoiding the application of such chemicals to other plants. The practical and economic needs for such a device are substantial. First, if not selectively applied, the herbicide may adversely affect the growing agricultural crop. Second, a substantial portion of a herbicide may be wasted because it is applied to the ground surface and not to the vegetation thus reducing the cost effectiveness of the chemical. Third, application of herbicide to the ground contributes to pollution and long term unknown environmental problems. Fourth, different herbicides have different effects upon different weeds and selective application of the correct herbicide to the proper weeds would achieve the most cost effective eradication.

The plant identification component of my invention may also be combined with a

1 mechanical weed eradicator such that the weeds may be selectively eradicated by a knife, water
2 jet or other tool upon identification of the undesirable plant or weed. In addition, it can be used
3 to selectively apply growth regulators, inhibitors and other chemicals to selected crop plants.

4 Illustrative of benefits and one field of use of this invention is the identification and
5 spraying of weeds in Roundup® corn or cotton, *i.e.*, plants whose genetics have been altered so
6 as to be unaffected by Roundup® herbicide. Presently, these crops are planted and the
7 Roundup® herbicide is subsequently applied over the entire crop, the ground and weeds of all
8 types. At a recommended application rate of a quart per acre and a cost of approximately \$37.50
9 per gallon, the farmer's total cost of applying the Roundup® herbicide may be \$10.00 per acre
10 for each application. Yet, in many fields, less than 10% of this amount of herbicide is needed to
11 kill only the weeds. This invention permits identification of the weeds and limited, but direct
12 application of herbicide to the weeds for a cost savings that may well approach \$9.00 per acre in
13 many applications. And clearly, where Monsanto Corporation, the manufacturer of Roundup®
14 herbicides, recommends two or more applications to the Roundup® corn or cotton, this
15 invention will permit substantial savings in the cost of growing these crops.

16 This invention also applies to the identification of other plants and the application of
17 other chemicals to those plants. For example, growth inhibitors are applied to crops in some
18 years to limit the growth of the plant while simultaneously enhancing the fruit production of the
19 crop. This invention will permit the selective application of the inhibitor to the plant without
20 excess application to the ground and the weeds.

21 The invention of this application also applies to the field of plant stress and condition
22 analysis. Its capacity to collect wide spectrum light data reflected from a plant enables the use of

1 the invention to quantify the condition of the plant, including the existence of plant stress at a
2 very early stage. More importantly, the invention permits the collection of detail wide spectrum
3 information that cannot be read by the human eye. Such is believed to provide early revelation
4 of the need for fertilizers, moisture, growth inhibitors, or the presence of nematodes and fungi.
5 Importantly, the invention permits an objective method of analyzing plants that avoids subjective
6 and varying interpretations and conclusions that might otherwise result from individual
7 observation.

8 This invention also has application in other fields such as identification of the condition
9 of plants and objects including fluids and animal tissue. For example, it may be applied to the
10 identification of the ripeness and grading of fruits and vegetables such as tomatoes, quality
11 control of the color of finished objects and the identification of normal, diseased or abnormal
12 tissue in the human body directly or through a scope.

13 **The Prior Art.** The prior art has long recognized the problem and need for plant
14 recognition and the application of chemicals only to certain plants. In this decade one popular
15 approach is a spray vehicle having a support bar with seats for three or more laborers holding
16 manually operated spray guns. As the vehicle travels down the rows at a slow speed, the
17 laborers selectively apply a herbicide to any weeds encountered. This is one expensive effort
18 to eliminate the common practice of hoeing weeds in crops such as cotton. In addition to this
19 approach, substantial efforts have been made to develop improved plant identification
20 methods. In large part, the art has focused on the broad identification of vegetation through
21 two basic methods: 1) spatial detection by plant location in the middle of the rows by
22 mechanical means and 2) detection by the use of light such as breaking a light beam or

1 reflection comparison of light beams composed primarily of red and infra-red light
2 wavelengths or of a few wavelengths of light such as the primary colors.

3 For example, U.S. Patent 4,206,569, which issued in 1978 to Randolph, teaches the
4 detection of undesirable plants by their position between rows of plants. In one embodiment,
5 Randolph teaches the use of a “feeler paddle” to physically feel or sense the position of a plant
6 within the row and to actuate a switch which, in turn, activates a sprayer to apply a herbicide to
7 the plant. In another embodiment, the Randolph patent teaches the use of an infrared light
8 source and sensor to detect the presence of a weed between the rows of plants. Interruption of
9 the infrared light beam indicates the presence of a weed that causes activation of a solenoid
10 valve which applies herbicide to the plant.

11 U.S. Patent No. 5,144,767 which issued in 1992 to McCloy *et. al.* discloses an
12 agricultural sprayer that detects the presence of vegetation by sensing the reflected red and
13 infrared wavelengths and the incident light energy. Subsequently, a CPU determines the ratio of
14 reflected red and infrared light to the incident light, compares them with those of a lookup table
15 that is tailored with values indicative of vegetation. If there is a comparison, then a herbicide
16 spray is applied to the vegetation. McCoy notes that his device identifies green vegetation
17 because it is “quite dissimilar to all other surfaces when analyzing the reflectance values of both
18 wave-bands,” *i.e.*, the red and infra-red wave bands. McCoy does not suggest any capability to
19 distinguish between types of green vegetation, *i.e.*, between weeds of different types or between
20 weeds and crop plants.

21 Another prior art device is that advertised as the Patchen TM Selective Spray Systems of
22 101A Cooper Court, Lost Gatos, CA 95030, a company that is believed to be a wholly-owned

1 subsidiary of Deere & Company of Moline, Illinois. On belief, this unit uses reflections from
2 bursts of light to distinguish between soil and weeds that are spatially located in the middle of
3 the row. A Patchen advertisement states:

4 "The spray system will spray only weeds, not bare ground. Make No
5 mistake—this is a revolutionary achievement that will deposit dollar savings
6 directly into you bank account."

7 As far as can be determined, this unit has some ability to distinguish between plants and bare
8 ground, but not between crops and weeds. Neither can it identify specific types of weed.
9 Patents numbered 5,763,873, 5,585,626, 5,389,781 and 5,296,702 are believed to be directed to
10 this device. They represent at least six years of development work in this field.

11 SUMMARY OF INVENTION

12 The present inventions are primarily directed to a wide spectrum light scanning and
13 sensor unit having a digital identifier. The preferred application focuses on a low cost plant
14 identifier or recognition system that may be mounted upon a moving vehicle for accurately
15 identifying and distinguishing between different species of plants at conventional agricultural
16 spraying speeds. This identifier may be combined with an apparatus for selectively applying
17 herbicides, plant inhibitors, growth regulators, or selectively actuating a tool such as a knife or
18 water jet for eradicating the plant. Other applications include grading of fruits and vegetables,
19 analysis of plant and animal tissue, etc.

20 The preferred embodiment of the plant identifier includes an electromagnetic sensing
21 mechanism that is not limited to identification premised upon a few wavelengths of light such as
22 red and infrared. This invention is preferably, an accurate wider spectrum electromagnetic

1 method and apparatus capable of accurately identifying and discriminating between different
2 types of vegetation as well as between vegetation and soil of any type and color.

3 The invention includes a wide spectrum scanning and sensing unit that having slits
4 through which reflected light is transmitted to a lens and through an associated diffraction
5 grating which separates the light according to its wavelength. The separated light impinges upon
6 a linear sensor array of pixels within the unit which identifies both the relative wavelength and
7 the intensity of the light. Each pixel develops a voltage indicative of the light received. An
8 output is taken from each of the pixels to define the spectral distribution of light reflected by a
9 plant. This spectral distribution defines a "fingerprint" of each species of plant to distinguish
10 one species from another. If desired, the fingerprint can be transferred to and plotted on an
11 oscilloscope (wavelength or pixel location vs. magnitude) for immediate visual examination of
12 the resulting fingerprint of the plant, object or tissue.

13 This fingerprint or wide spectrum sensing unit also has the capability of identifying the
14 condition of the plants or tissue. For example, it is believed that the spectral distribution will
15 reflect and identify conditions such as plant stress including a lack of moisture, the need for
16 nutrients, the presence of nematodes, etc. To accomplish this function more accurately, it may
17 be desirable to read more pixels from the linear sensor array or to resort to a higher capacity
18 linear sensor array. To accumulate data reflecting a crop condition, this invention may include a
19 transmittal element such as RS 232 port to permit transmission of the spectral distribution of
20 sample plants within a field to a distant receiver or to a portable computer for subsequent, high
21 speed analysis of the condition of the plants.

22 For plant identification, outputs from the pixel array of the sensing and scanning unit are

1 converted from analog to digital signals and transmitted to a micro controller or comparator
2 which first memorizes the fingerprint of the plants desired to be identified. Thereafter, the
3 tractor and tool bar moves through the crop to generate time interval reflected spectral
4 distributions (frames) of plants within an agricultural crop. These reflected distributions or
5 fingerprints of each frame of other plants are then compared with a memorized spectral
6 distribution of the plant species sought to be identified. If there is a comparison, the identified
7 plant can be sprayed or acted upon in accord with a preset mode.

8 Preferably, the digital identifier is a micro controller programmed to first memorize a
9 plurality of wavelengths of light reflected by one or more plants to define the "finger-prints" of
10 the plants of interest, to subsequently receive additional reflected wavelengths from other plants
11 in timed intervals as the vehicle moves through the field and to immediately compare the
12 reflected wavelengths to the memorized wavelengths. If the comparison reflects that the
13 received wavelengths are substantially similar to the memorized wavelengths or finger-prints,
14 the plant can be sprayed, not sprayed or eradicated in accord with a selectable program.

15 Preferably, but not necessarily, the comparison made by this invention comprises a
16 regression analysis to determine the coefficient of correlation between the memorized and the
17 sensed spectral distributions. If there is a high coefficient of correlation, the micro controller
18 emits a signal to treat the plant in accord with programmed instructions, *i.e.*, a solenoid valve
19 may be opened to permit a pump to spray the identified weed or closed so as not to spray the
20 plant, etc. The limit of the coefficient of correlation may be varied to meet any desired certainty
21 of plant identification.

22 Accordingly, the goals and objectives of this invention are to provide, among other

1 things,

2 1) a method and apparatus for substantially reducing the cost of applying herbicides to
3 selected or undesirable plants;

4 2) a method and apparatus for substantially reducing the cost of applying herbicides to
5 selected plant species by identifying plants of the selected species and by applying herbicides
6 only to those species;

7 3) a method and apparatus of selectively applying chemicals such as herbicides, growth
8 regulators and inhibitors to selected plants rather than to the entire population of plants within a
9 crop field so as to reduce the cost of chemicals and to reduce the possible adverse environmental
10 effects;

11 4) a very accurate multi-wavelength spectral plant identification and recognition method
12 and apparatus;

13 5) a method and device for reading, transmitting and accumulating the very accurate
14 fingerprint or spectral distribution of plants for analysis of plant conditions such as stress
15 resulting from lack of moisture and nutrients and the presence of nematodes;

16 6) a method and apparatus for identification of stress conditions of a plant prior to visual
17 recognition of such conditions by the human eye through the use of a full spectrum fingerprint of
18 the wavelengths reflected by the plant;

19 7) an apparatus for obtaining objective definitive digital information of the condition of an
20 object or plant which avoids subjective conclusions drawn upon visual personal examinations;

21 8) a multi-wavelength spectral plant identification and recognition device using a low cost
22 diffraction gratings, and a light sensor array;

1 9) a low cost, wide spectrum electromagnetic plant identification method and apparatus
2 using a low cost diffraction grating, and a light sensor array and a memory device for storing a
3 fingerprint of the spectral distribution of a plant;

4 10) a wide spectrum electromagnetic plant identification apparatus and method having the
5 ability to memorize a wide spectrum identification of one plant species and to compare that
6 memorized identification with spectrum identifications of a number of plants so as to identify
7 plants that are similar or substantially similar to the memorized plant species;

8 11) an accurate plant sensing mechanism with a plant action mechanism so as to
9 selectively apply an action to all identified plants of a particular species;

10 12) a simple, low cost, minimum maintenance apparatus and method for identifying
11 species of plants or other objects at high speed;

12 13) a simple, lost cost, minimum maintenance apparatus and method for identifying,
13 grading or selecting objects, plant and animal tissue by their color reflections,

14 14) a low cost spectroscope and identifier that does not require costly physical calibration;

15 15) a low cost scanning, sensing and identification unit that can use software for
16 calibration and identification of plants, tissue and other objects;

17 16) a low cost scanning and sensing device having a target or aiming system to identify
18 the area and object whose spectral image is being generated; and

19 17) a light scanning and sensor unit having a digital identifier for selectively identifying
20 and evaluating objects, plant and animal tissue of different colors for purposes of evaluation,
21 processing, etc.

DESCRIPTION OF THE DRAWINGS

The manner in which these objectives and other desirable characteristics can be obtained from this invention is explained in the following specification and attached drawings in which:

Figure 1 is a perspective view of a preferred embodiment of the invention depicting the plant identification unit and its association with a solenoid controlling a spray rig, the invention being mounted on the tool bar of a farm tractor;

Figure 1a is an enlarged perspective view of the preferred plant identifier unit and spray unit of this invention;

Figure 2 is a block diagram depicting all of the major components of a preferred embodiment of the plant identifier invention;

Figure 2(a) is a chart depicting the functions of the software to be incorporated into the microprocessor;

Figure 3 is a circuit diagram of the preferred electronic schematic layout including the micro controller to be used in the apparatus and method for identification of plants;

Figure 4 is an illustrative drawing of a preferred embodiment of the optical scanning and sensor unit;

Figure 5 depicts "fingerprint" graphs of the cotton plant and the night shade weed actually generated by the present invention in which the wavelength (pixel location) of the plant and weed are depicted on the horizontal axis and the magnitude of the reflected light is depicted on the vertical axis to define the spectral distribution of each, (the data points of the wavelengths are estimates since the pixel output was not calibrated by wavelength);

Figure 6 is block diagram depicting additional components of a preferred embodiment of

1 the plant identifier invention together with alternatives for transmitting the plant's spectral
2 reflectivity, the plant's identity and its condition to a remote data collector such as computer;

3 Figure 6 (a) is a flow chart disclosing additional functions of the software program to
4 enable the microprocessor to collect and transmit data reflecting the plant's color spectrum for
5 the purpose of identifying its species or its condition; and

6 Figure 7 is an illustrative, schematic view of an alternative embodiment of the optical
7 scanning and sensor unit having a light beam for aiming at or targeting the plant or object whose
8 spectral image is being scanned.

9 **DETAIL DESCRIPTION**

10 As depicted in Figure 1, the preferred embodiment is mounted upon a tool bar 10 that is
11 affixed to a farm tractor whose left rear wheel is shown at 12. This preferred embodiment
12 includes a plurality of plant recognition or scanning and sensor identification units 20. These
13 units may take various arrangements. In the embodiment shown in Figure 1, these units are
14 positioned side by side and are directed to emit light downwardly and to receive reflections from
15 a row 16. Additional units may be mounted and directed to sense plants on or adjacent the seed
16 bed 18. As will be appreciated, the total number, location and directional mountings of these
17 identification units 20 will be dependent upon the expected size of the plants, the desired
18 accuracy, *etc.*

19 In operation, these identification units 20 will travel with the tractor and tool bar 10
20 down the rows 16 at high speeds of up to 12 miles per hour or more. Consequently, the plant
21 sensing units must scan or take timed plant images (frames) at a very high rate, transmit the
22 images to a comparator or processor to quickly determine if the reflected image is from a plant

1 to which a herbicide or other chemical should be directed. If so, a control or actuation signal is
2 transmitted from a controller to a solenoid 60 to apply a herbicide spray from a pump (not
3 shown) through a nozzle 62 to the plant 80 before the tractor unit has traveled out of spray range
4 of the plant.

5 **THE PLANT SPECIES IDENTIFIER**

6 Figure 2 schematically illustrates the design and effective use of the preferred
7 embodiment of this invention for plant identification purposes. After power is applied, the
8 processor initiates its system and program routines. Thereafter, a simple set up is required by the
9 user who must first obtain a "sample" or "standard" species of the plant to be subsequently
10 identified by the invention. A spectral distribution of the light reflected by this "sample" plant is
11 diffracted and placed into the memory of the digital identifier or micro controller 36. An
12 acceptable digital identifier or micro controller capable of serving this function is that
13 manufactured and sold by Motorola, Inc. of Schaumburg, IL under the model designation
14 68HC705C8. This controller 36 has substantial memory and can receive and store a spectral
15 distribution of reflected, discrete wavelengths of reflected light from the plants to be treated. In
16 addition to data memory, it also has program memory and pins to actuate the functions of
17 managing peripheral devices and to carry out the desired comparisons between the digitized
18 fingerprints of the memorized plant species with the reflected fingerprints.

19 To place the "sample" or "standard" species into the programmed controller, the user or
20 farmer positions the sample of the selected plant in front of a sensing unit 20. Natural or
21 enhanced light from a high intensity lamp 24 is reflected from the plant into the scanning and
22 sensing unit 20 (outlined by dotted lines in Figure 2). Side plates 25 form slits or vertical

1 apertures 26 to insure that the light is directed through a lens 28 having a focal length, preferably
2 of 1 inch, to a diffraction grating 30. Preferably the diffraction grating has 1,000 lines per meter.
3 This grating 30 breaks the reflected light into discrete wavelengths and directs it to an array of
4 linear arranged sensors 32. Those skilled in the art will appreciate that a prism may be an
5 adequate substitute for the diffraction grating.

6 The array of sensors may be a TSL 1301 array manufactured and sold by Texas
7 Instruments, Inc. of Dallas, Texas. It includes 102 sensing elements or pixels, each comprising a
8 PN junction. Some or all of the sensing elements may be selected to receive the diffracted light
9 wavelengths and to generate or accumulate, upon inquiry, a voltage charge proportional to the
10 intensity of the received wavelength. To reduce the memory required and for ease of
11 programming, 32 of the 102 pixels have been found to be sufficient for plant identification
12 purposes. This allows for fingerprint definition of the plant comprising 32 different wavelengths
13 and a rather accurate spectral distribution of the plant. Generally, these 32 wavelengths will
14 represent a very wide, if not full spectrum of light extending from about 400 nanometers to
15 about 1100 nanometers. If desired, other sensor arrays could be used to identify shorter or
16 longer wavelengths including infra red lengths.

17 In operation, each of these pixels develops a voltage that correlates to the quantity of
18 light received. This developed voltage by each pixel can be read by the micro controller 36. For
19 this purpose, controller 36 has a switch 64 (see Figures 3 and 4) to enable the farmer to manually
20 instruct the unit to pulse the sensor array 32 to obtain spectral distribution of the "sample" of
21 "standard." This pulse signal will sequentially generate an analog output from all of these pixels
22 to the sensor array 32 and transmit them to an analog-to-digital converter 34. The converter 34

1 will then direct digital information corresponding to the magnitude of the voltage developed by
2 each pixel into one of 32 memory elements of the micro controller 36 for storage and
3 comparison purposes.

4 When stored (memorized), the micro controller 36 then has a spectral distribution or
5 “fingerprint” of the wavelengths reflected by the plant to be identified in the subsequent
6 fingerprinting operation in the field. This memorized print thus becomes the “standard” against
7 which subsequent or fingerprints are compared. The spectral distribution of the plant to be
8 identified can also be transmitted to the other sensing units 20 via a serial communication port in
9 the 68HC705C8 micro controller. This port can be tied to the corresponding ports of each light
10 scanning and sensor unit 20 and an appropriate program can be written to allow any one of the
11 units to communicate the spectral distribution of the wavelengths reflected by the plant to each
12 of the other units in the system for ease of set up.

13 It should be noted that plants to be identified do not have a uniform finger print under all
14 soil, moisture and atmospheric conditions. Thus, the present invention permits the farmer to
15 specifically place in memory the spectral distribution or fingerprint of the plants to be selected
16 for treatment on his farm under the then existing conditions. Such facilitates an accurate plant
17 identification and minimizes error that may result from soil moisture conditions, fertilizers,
18 pests, temperatures, etc. Similarly, the capability of this invention to receive and memorize
19 specific plant fingerprints from the actual farm to be sprayed eliminates the need and costs to
20 develop predetermined fingerprints for dozens of plants. For the first time, such can be done on
21 site. Significantly, an original aspect of this invention is its ability to generate its own
22 fingerprints by directly focusing on the plant, tissue, object or an actual replica or photo

1 representative thereof without the use of prerecorded digital or analog data points. Figure 5
2 depicts the spectral distribution or graphical fingerprints of two plants that many farmers would
3 like to identify. One curve reflects the fingerprint of a cotton plant that may be used to avoid
4 application of herbicides or to apply a growth inhibitor. The other curve reflects the fingerprint
5 or spectral distribution of a prevalent, noxious weed, the nightshade in West Texas, these
6 distributions being taken by the present invention. From a comparison of these two curves, it is
7 apparent that they are different and that a regression analysis would generate a very small
8 coefficient of correlation advising of the dissimilarity of the two plants. After the plant, such as
9 the night shade has been fingerprinted by memorizing its wavelength output, the unit is ready to
10 identify all of the plants in a field having the same finger print or "spectral distribution" of
11 wavelengths. This comparison of the spectrum distribution of reflected light from nightshades
12 with that from cotton in Figure 5 manifests the different fingerprints of these two plants so as to
13 permit their selective identification. It also demonstrates a capability to permit set up and
14 identification of each plant by a sample leaf. Alternatively, the generation of a single fingerprint
15 on an oscilloscope will permit immediate visual identification of the type or condition of the
16 plant or tissue if such is desired.

17 Assuming that the farmer's decision is to spray all of the plants of the memorized species
18 with a herbicide such as Roundup®, the farmer fills the herbicide reservoir or sump S of Figure
19 2 with a proper solution of Roundup®, initiates a pressure buildup by the pressure pump P
20 which is connected to a solenoid valve 60 having a spray tip 62 which is directed at the same
21 area and along the same axis as the scanning unit 20. A solenoid driver 44, controlled by the
22 micro controller 36 activates the solenoid valve 60 to spray the herbicide on the plant.

1 To insure that the memorized plant is identified and sprayed before the tractor unit
2 passes the plant, the micro controller 36 must first identify the plant as one to be sprayed and
3 then immediately actuate the solenoid valve 60.

4 To obtain this instantaneous, but very accurate plant identification, the microprocessor
5 36 is programmed to initialize reading the individual pixels of the linear sensor array 32
6 preferably at least once every 25 milliseconds. Such has been calculated to permit identification
7 of a plant having a leaf width of approximately 2.5 inch width while traveling at speeds of
8 approximately 5 miles per hour. Thereafter, each clock pulse serially reads the voltage generated
9 by each pixel or sensor to define a spectral image, frame or fingerprint. This voltage is
10 converted to digital information and then stored in other data memory locations of the micro
11 controller 36. After the sensors are read and their output stored in the micro controller 36, the
12 memorized (standard) spectral distribution is compared with the spectral distribution of that
13 reflected by the last plant. While only a few wavelengths could be compared to obtain a
14 reasonably accurate determination of the similarity of the memorized plant distribution with that
15 of the reflected plant, the preferred embodiment of this invention includes programming of the
16 micro controller 36 to run a statistical regression analysis comparing the data points of the
17 spectral distribution or wave chart of the memorized plant with the reflected spectral distribution
18 of each time out-put or frame of the reflected spectral distribution. If the coefficient of
19 correlation between the two distributions is high or greater than the pre-set limit so as to reflect
20 similarity or identity, the micro controller 36 generates an output to the solenoid driver 44 to
21 activate the solenoid valve 60 to apply spray.

22 Fast acting solenoids such as those sold by Peter Paul Electronics Co. Inc. under the

1 trade mark or model number 32X005806 are sufficient. Spray tips 62 can be selected to apply a
2 very narrow target spray or a wider one depending on the desires of the farmer and the need for
3 accuracy. For example, if one is applying a Roundup® herbicide to nightshade weeds in a
4 Roundup® variety of cotton, some over-spray will not damage the crop and will merely result in
5 a limited over-spray that affects costs and pollution in a limited way. On the other hand, the
6 required coefficient of correlation between the two plant fingerprints may be increased to obtain
7 higher certainty of plant recognition and a finer spray tip can be selected to more accurately
8 direct the herbicide to the identified weed and nothing else. Those acquainted with the art will
9 also recognize that a timing of the activation and duration of the solenoid can be used to actuate
10 the solenoid at a later time or distance so that the solenoid can be activated a fixed distance after
11 the weed is detected thus allowing the spray to take place a fixed distance behind the
12 identification to avoid contaminating the optical system with chemical. If the solenoid is of a
13 type to be deactivated, then the program of the micro controller can include such a function.

14 It should be appreciated that the micro controller 36 must be very fast and should read
15 the memorized images and run a regression analysis numerous times per second to insure that
16 each weed or plant is scanned for its spectral distribution and considered for spray by the
17 regression analysis.

18 Figure 3 depicts an electronic circuit board design 46 that has been demonstrated to be
19 effective for the purposes of this invention. The controller or digital identifier 36 is located on
20 the left side of the board 46. Leads 48 and 50 prepare (SI) and initiating (CLK) data
21 communication of the analog magnitude contained in each of the sensors of the array 32. This
22 accumulated data is communicated to the analog-to-digital converter 34 via lead 52. The analog

1 to digital converter 34 converts the analog signal to a binary digital signal and delivers the result
2 to port C, *i.e.*, pins 21 to 28 or (PC0 through PC7), of the micro-controller 36. A timer built into
3 the micro-controller 36 repeatedly generates a clock pulse to take a new fingerprint of its visual
4 area and deliver the fingerprint or spectral distribution in binary form to the micro-controller 36.

5 The reference circuit 54 at the lower right of Figure 3 supplies an upper reference for the
6 analog to digital converter. This is set to the highest expected value of the analog output signal
7 52.

8 After each time interval light data is fed into the micro controller 36, it runs a
9 preprogrammed regression analysis to determine the coefficient of correlation between the
10 spectral distribution of the memorized plant and the spectral distribution of the plant of the new
11 time interval frame. If the coefficient of correlation is equal to or greater than a predetermined
12 value, the micro controller emits a signal through the solenoid driver 44 to activate the solenoid
13 60 to spray identified nightshade plant. Preferably the result of the correlation computation is
14 converted to an integer factor that is representative of the coefficient of correlation so as to
15 simplify the spray decision and avoid a decimal number.

16 The pre-set value or correlation limit established for actuation of the solenoid driver 44
17 can be increased as desired through discriminating switches 56 and 58. The non-grounded side
18 of the more discriminating switch 56 is connected to pin 15 of the micro-controller 36. When
19 this pin is activated, the program in the controller increases the limit of the correlation
20 coefficient by $1/256$. When pin 16 of the micro-controller is activated by pressing the less
21 discriminating switch 58 the correlation coefficient limit is decreased by $1/256$. The increment
22 value, $1/256$, may be decreased by a software change for greater accuracy.

1 A standard switch 64 may be used to instruct the micro controller 36 to memorize the
2 spectral sample (or standard distribution) in a specified portion of its memory to be used in
3 subsequent calculations of the correlation coefficient or its factor. This allows the unit to spray
4 only things that are like the sample or only things that are not like the sample. As those skilled
5 in the art will appreciate, an alternative method of accomplishing this task would be the use of
6 switches connected to a micro controller pin and software to change the logic mode. For
7 example, instead of identifying plants to be sprayed with a herbicide, the invention can be set up
8 to identify the planted or money crop—and use an inverter to spray all other vegetation. Thus,
9 the mode switch 66 can be used to change from the mode that actuates the solenoid 60 (Figure 4)
10 when the correlation coefficient limit is exceeded to a mode where the solenoid 60 is deactivated
11 when the correlation coefficient limit is exceeded.

12 To facilitate one's understanding of this invention, the flow chart of Figure 2(a) further
13 discloses the functions of the software of the micro controller 36 as described herein. In
14 addition, these functions have been incorporated into the following machine code for the
15 identified Motorola micro controller MC68HC705C8 in a manner to utilize 32 pixels of the light
16 sensor array so as to 1) effectively memorize a spectral distribution of a sample plant, 2) to
17 subsequently take spectral distributions (fingerprints) of other plants, 3) to compare those plants
18 with the sample, and 4) to identify the other plants that are of the same species or spectral
19 distribution as the sample.

20 MACHINE CODE

21 S1130100A620B777A60FB7BBA600B7BFC61FDFAA46
22 S113011082C71FDFA6A7B704A600B706A6E7B705E0
23 S11301203F02A690B7BBCD044ECD0169CD01840D2D
24 S1130130000BA600B7BFB778B7BDCC0141A601B785
25 S1130140BFCD045D00BF022000CD04D9CD04C0CDD5

1 S1130150019FCD01CECD01FDCD022D1B00BE42B3CA
2 S1130160772503CD04F2CC0126060115003B1410BB
3 S11301703BB677AB01B777A1402508A640B77720F7
4 S113018002113B81080115023B14123BB677A00112
5 S1130190B777A1012208A601B7772002133B81A6F5
6 S11301A000B7B5B7B4B7B3BFBCAE425CA363271DF9
7 S11301B0BFB6F6FECD0504BBB5B7B5BFBEB6BEB976
8 S11301C0B4B7B4A600B9B3B7B3BEB620DE81A600F7
9 S11301D0B7B2B7B1B7B0BFBCAE785CA399271DBFA7
10 S11301E0B6F6FECD0504BBB2B7B2BFBEB6BEB9B15A
11 S11301F0B7B1A600B9B0B7B0BEB620DE81A600B7CD
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S9030000FC

Figure 4 depicts one mechanical arrangement for the scanning and sensor unit 20. As shown, each entire light scanning and sensor unit 20 is contained in a housing 22 that is formed of rectangular tubular stock. To the rear of the sensor unit 20 is mounted the circuit board 46. A light source 24, preferably Sylvania lamp MR 6 is affixed in similar tubular stock adjacent the housing 22. Light is reflected from an object to the right and is reflected through the shield 68 and apertures 26, through lens 28 and diffraction grating 30 which diffracts the light the longer wavelengths through a larger angle than the shorter ones. The result is a rainbow of light on sensor array 32 with infrared to the bottom and ultraviolet at the top and all parts of the visible electromagnetic spectrum in between.

ALTERNATIVE EMBODIMENTS, MODES AND METHODS.

1 Persons skilled in the art will appreciate that the disclosed scanning and identification
2 invention can be utilized in several ways and is not limited to a specific mode. As earlier
3 mentioned, a mode switch 66 can be used to control the output of the micro controller so that it
4 sprays the vegetation having a high correlation coefficient to the sample, or so that it does not
5 spray that vegetation. In addition, the planted crop can be fingerprinted, identified and sprayed
6 with growth inhibitors, etc. rather than herbicides. Another alternative mode of operation of this
7 invention can be obtained by placing the fingerprint of two or more samples of plant species into
8 memory, and programming the micro controller to run two or more comparisons or regression
9 analysis before issuing a determination to actuate the sprayer or other device. This mode and
10 modification can take several forms. For example, if a farmer desires to spray two weeds with
11 different herbicides, he could associate one regression analysis with one solenoid driver and
12 herbicide sprayer and a second regression analysis with another solenoid driver and herbicide
13 sprayer. Such is a desirable capability when different herbicides have different effectiveness on
14 different plants. In addition, the farmer might hold a soil sample under the sensor unit and place
15 its spectral distribution in memory. Should the comparator then determine that the compared
16 time interval spectral distribution is the same as that of the memorized soil sample, the
17 microprocessor can be programmed not to spray. This mode would permit the spraying all
18 vegetation, but not the bare ground.

19 In addition to the soil sample spectral analysis, a farmer might store a second distribution
20 of the cotton plant of Figure 5. After the microprocessor runs a regression analysis comparing
21 the reflected distribution with each of the soil and cotton plant distributions, it can easily be
22 programmed or provided with a separate logic board to activate the sprayer only if neither cotton

1 nor soil is detected.

2 Those skilled in the art will also appreciate, that rather than using a single micro
3 controller 36 to memorize two or more plant or soil spectral distributions, one might use two or
4 three units and focus them on the same frame or image. Each unit could memorize a single
5 distribution and identify a single object or plant species. The output of these separate devices
6 could be input to a logic board with switches that would permit any of the commonly known
7 logic decisions such as those of AND, NAND, OR, NOT etc. logic gates. In addition, the present
8 invention can take many forms and utilize numerous components that perform in substantially
9 the same way to achieve substantially the same result. For example, numerous controllers or
10 digital identifiers could be used in lieu of the Motorola controller disclosed in this specification.
11 Those skilled in the art will appreciate that the essential functions of the digital identifier or
12 controller 36 are those of providing memory for the storage of the spectrum data and of the
13 program steps reflecting the desired functions as well as logic circuitry having the ability to
14 perform the desired functions and comparison. Such may take the form of an arithmetic logic
15 unit or its equivalent. In addition, the digital identifier should have an Input/Output (I/O)
16 capacity to receive data from the sensor array and to control at least one peripheral device such
17 as the sensor array 20. Preferably, the identifier will have input and output pins to activate the
18 solenoid and to receive the data reflecting the spectral distribution or to transmit the information.
19 Consequently, any of the various micro controllers, computers, microprocessors and digital
20 signal processors (DSP) which have the necessary components will be acceptable alternatives.
21 Alternatively these individual devices such as the memory and I/O devices can be purchased
22 separately and wired together to accomplish the necessary functions.

1 More specifically, one alternative is a Digital Signal Processor (DSP) Model No
2 TM320F240 which is made and sold by Texas Instruments of Dallas, Texas. In addition, Model
3 No. TMS 320F243 has the capabilities to meet the requirements of this invention. These units
4 provide enhanced features such as high speed (20 megahertz), additional storage and the ability
5 to point to two sets of data simultaneously. In addition to the use of alternative processors, those
6 skilled in the art will appreciate that different lamps may be utilized and that in many cases, the
7 lamp will not be necessary with natural light being sufficient. Too, alternative array devices that
8 are more sensitive or have different pixel counts may be utilized instead of the TSL 1301. For
9 example, TSL 1401 from Texas Instruments, Inc. of Dallas, Texas will permit the collection of
10 128 wavelength sectors rather than 102. And though the invention preferably uses a regression
11 analysis to develop a coefficient of correlation, the invention may well provide the desired
12 accuracy of plant identification by merely comparing only three or four data points of the light
13 spectrum. This could be accomplished by use of 3 or 4 discrete sensors properly located to sense
14 the desired wavelengths of light and a simple comparison program that does not require a
15 regression analysis or computation of the coefficient of correlation. A multiplicity of linear
16 arrays or an area array, could be used to reduce the number of sensor units, with each column
17 representing spectral information equivalent to one sensor unit. Advantage can also be taken of
18 the opportunity to develop statistics regarding the precise location of the edge of the canopy and
19 the texture of the field of view with such numerical methods as fast Fourier transforms,
20 convolution, and other recognition methods including statistical process control techniques such
21 as mean and standard deviation control chart theory. With a multiplicity of elements, or an area
22 array in which each column represents the spectral reflectivity of a point on a line across the crop

1 row, repeated samples, taken in time as the motion of the unit continues through the field,
2 spectral image data is generated and digital filtering methods can be applied to get an image of
3 the desired object, weed or other plant or feature. Another alternative would be to utilize a
4 previously memorized spectral distribution in the form a memory or data card to set up the unit
5 and to establish the initial electronic memory or finger print rather than using an actual plant.
6 Illustrative of further alternatives is the use of digital filtering and transforms which can be used
7 to enhance recognition capability.

8 An alternative embodiment of the scanning and sensing unit 20 is depicted in Figure 7.
9 This improved alternative 120 includes an aiming or target light to facilitate identification of the
10 plant or object which is being scanned. This unit includes a housing 122 which houses two
11 lenses 140 and 142 that are positioned equidistant from an aperture plate 125. Affixed to the
12 housing 120 in any conventional manner is a light source 124 that is focused upon a plant 80.
13 Light reflected from the plant passes into the housing 122 through the lens 140, the aperture
14 plate 125 and the second lens 142 to the diffraction grating 130. Segments of this reflected light
15 are diffracted upon the sensor array 132 which is offset from the housing 122. In operation, this
16 unit works in a manner similar to that of scanning and sensing unit 20.

17 In addition, however, a Target Light is mounted to the right of the housing 130, as
18 viewed in the drawing. This light source, when activated, transmits light in the opposite
19 direction of the reflected light, *i.e.*, it passes into the housing 122, through lens 142, aperture
20 plate 125, lens 140 where it is focused on a part of the plant 80. When the Target Light source is
21 activated in any conventional manner, the focused light will be apparent on the same portion of
22 the plant as the light would be reflected from lamp 124. Accordingly, when activated, the target

1 light source will identify the actual target of the scanning and sensing unit 120. Importantly, this
2 target light will inform the user whether the spectral sample is of the plant leaf, stem, flower etc.

3 Preferably, the Target Light and the lamp 124 will not be actuated at the same time.

4 Those skilled in the art will appreciate that the focal point of the target light and its
5 distance from the housing will be dependent on the selection of the lens 140 and 142 and their
6 placement within the housing.

7 **THE PLANT CONDITION IDENTIFIER AND TRANSMITTER**

8 Another embodiment of the invention is depicted in Figure 6. This embodiment depicts
9 additional components for and methods of using the digital identifier to collect and transmit
10 plant fingerprints or wide spectrum data points of plant or tissue immediate evaluation or for
11 accumulation and subsequent analysis of the object.

12 In this embodiment, a toggle switch 80 is used to switch the controller program from one
13 of plant identification to one of plant analysis, *i.e.*, to the accumulation of a fingerprint or wide
14 spectrum data point collection and its transmittal to an oscilloscope, computer or to a memory
15 device for analysis. Alternatively, the data can be communicated to a portable computer
16 physically connected to the device for plant condition analysis.

17 Physically, this embodiment is physically similar to the plant identification embodiment
18 in that most of the same components are utilized. In addition, this embodiment has the mode
19 switch 80 to activate the transmittal program routine and a send or transmit switch 82. When
20 activated the transmit switch 82 instructs the processor 36 to serially transmit the entire full
21 spectrum of the plant's condition to a RS 232 port 92 which may be connected to a portable
22 computer or a radio transmitter or a digital cellular device. In addition, the processor 36 may be

1 programmed to receive a signal, such as character "0" from the computer and to serially transmit
2 the entire full spectrum of the plant sample to the computer where it may be stored for later
3 analysis.

4 In operation of this embodiment, a program is written to reflect the software functions
5 set forth in Figure 6(b) which is then stored in program memory of the processor 36. When the
6 mode switch 80 is activated, the light sensor accumulates a voltage charge in each of the pixels
7 to reflect the spectral distribution of the light reflected by the plant. Such charges are
8 sequentially sent to the analog to digital converter 34 and then transmitted to data storage
9 memory locations within the processor 36. Preferably sample distributions are continuously
10 taken, converted and stored for possible transmission to a memory device through the RS 232
11 port.

12 The data is transmitted upon activation of the switch 82 or upon a reception from the
13 computer or cellular device connected to the RS 232 element 92. In addition and as an
14 alternative to the use of the processor 36 to effect this transmission function, one may obtain the
15 analog output from the sensor array 32 by a direct connection at 94 to the output of the sensor
16 32. Such a connection has been helpful in directly connecting the unit to an oscilloscope (not
17 shown) to visually examine the spectral distribution of the light reflected by the plant. If desired,
18 a digital oscilloscope could be used to convert the analog information to digital for further use
19 and analysis by external means. In addition, a parallel connection 96 could be taken from the A
20 to D converter 34 and directed to an I/O card of a computer or other device.

21 Another modification to this embodiment is the use of a larger linear or area array.
22 Preferably model TSL 1401 or Texas Instruments, Inc. would be utilized because it has 128

1 pixels which can be utilized to obtain a more definitive fingerprint of the plant for analysis
2 purposes. Significantly such may be most helpful in ascertaining the degree of stress or other
3 conditions of the plant. In the event such a sensor is utilized, it will also be desirable to use an
4 enhanced processor such as DSP Model No. TMS320F240 previously mentioned.

5 Like the machine code program previously set forth in this application for the plant
6 identification routine, persons skilled in the art can easily formulate the collection and
7 transmittal program or routine for use in conjunction with either the single sample switch 82 or
8 the continuous mode switch 80.

9 In application, it is intended that the entire identification and transmittal units be
10 incorporated into a light weight hand held case to enable plant inspectors to carry the units to the
11 field, obtain spectral distributions of one or more plants or any part thereof and to transmit such
12 distributions to a memory device for subsequent analysis of the plant's condition. Alternatively,
13 such a unit could also be mounted on tool bars which are carried down the row with a computer
14 or controller transmitting the character "0" to the unit to effect transmittal or downloading of one
15 or more sample spectral distributions of the plants or crops at various points.

16 In implementing these inventions, those skilled in the art will also appreciate that the
17 spectrometer or scanning and sensing unit 20 of my invention may be calibrated. However,
18 calibration may impose additional costs. On belief, most if not all commercial spectrometers are
19 calibrated. However, an alternative is to avoid calibration and to approximately align a segment
20 of light rays, for example visible red light with, for example, the center pixel of the sensor array
21 32. Such should always be sufficient when the same spectral identifier unit is being used for the
22 sample and for the other objects of the population. This, for the reason that the same instrument

1 will always diffract the same wavelengths to the same pixels and the resulting comparison will
2 always be comparing the output of each wavelength of the sample with the output of the same
3 wavelength of the next object of the population.

4 However, when different instruments using an uncalibrated sensor and scanning unit of
5 my invention are used to generate the finger prints of objects or tissue, it may be advantageous to
6 insure that the digital identifier or comparator 36 or computer properly compares data points
7 generated by one scanning unit 20 with the appropriate data points generated by another sensing
8 and scanning unit 20. For example, the magnitude of the voltage generated by a diffracted wave
9 length segment of one sensing and scanning unit 20 should be compared and correlated with the
10 magnitude of the voltage generated by the same wave length segment on the other sensing and
11 scanning unit 20. Such would inherently result when using calibrated scanning and sensing
12 units. However, if one does not desire to use calibrated units or if one does not use the same
13 identifier unit to compare the fingerprints, it may be desirable to develop software that will
14 modify the wave length data points of the fingerprints of one identifier to match the
15 corresponding wave length data points of fingerprints of other identifiers. Such modifications
16 would require software shifting of the data points to insure that similar or identical sets of
17 wavelengths are shifted to a fixed standard for all manufactured units. Preferably, such software
18 would be incorporated into the memory of each of the digital identifiers 36 at the time of
19 manufacture and such would be a low cost form of calibration. Alternatively, such software may
20 be developed for a computer receiving transmitted fingerprints for analysis.

21 Those skilled in the various arts will also appreciate that the present inventions have
22 broad uses in other agricultural operations. For example, they might be used to identify specific

1 soils on a farm to selectively apply certain fertilizers to soils having certain colors. It may well
2 be used to identify and sort vegetables, fruits and other products by color and ripeness.
3 Similarly, the invention may well find applicability in numerous industrial, medical and
4 biological applications of collecting, identifying or processing products and objects including
5 fluids and animal tissue by color. Such uses may include the early detection of skin cancers.
6 Another diverse application would relate to color bar coding in which this invention would
7 facilitate the encoding and reading of far more information than the present black and white bar
8 coding. Other uses and modifications of this invention such as these will be apparent to those of
9 ordinary skill in the art from the contents of this application.

10